Probabilistic Stochastic Methodology for the Light-Matter Interaction

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Quantum mechanics has many curious interpretations, aiming to give a clearer qualitative description of particular phenomena, as well as to make numerical calculations less heavy. One of the examples is the replacement of the density matrix for a bosonic system with a quasi-probability distribution [1], leading to an intuitive probabilistic interpretation. If the studied process involves the interaction of at most two boson fields, the equation for the quasi-probability distribution becomes a Fokker-Planck equation that can be sampled with stochastic Ito differential equations.

There are several approaches to generalize this formalism and derive stochastic equations for fermions [2] or two-level atoms interacting with light [3]. However, the derivations typically require a series of approximations and do not allow simple extension to realistic systems. Fortunately, we managed to take a right angle to it and found a systematic, rigorous way of constructing the stochastic differential equations covering a wide variety of phenomena. These equations are not only convenient for the numerical treatment but also possess an intuitive structure. For instance, the interaction between multilevel atoms and continuum of field modes can be described – accounting for subtle quantum effects – by the equations similar to the Maxwell-Bloch ones. The only difference is that they include noise terms as a source. In the case of superfluorescence [4], these noise terms can be interpreted as the initial spontaneous emission triggering the radiation process.

In the talk, the key ideas leading to the derivation of general stochastic differential equations will be discussed, and the application for the case of superfluorescence will be demonstrated. By comparing our approach to the existing ones, the strong points of the introduced stochastic formalism will be highlighted. Other possible applications – that could benefit from the developed methodology – will be discussed.

References

[1] P D Drummond and M Hillery, The Quantum Theory of Nonlinear Optics, Cambridge University Press (2009)

[2] B J Dalton, J Jeffers and S M Barnett, Ann. Phys. **370**, 12 (2016)

[3] P D Drummond and M G Raymer, Phys. Rev. A **44**, 2072 (1991)

[4] M Gross and S Haroche, Phys. Rep. **93**, 301 (1982)